Design Aspects of the Microstrip Reflectarray

John Huang

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California, USA

Introduction: The Microstrip reflectarray has been identified as one of the enabling technologies to achieve low mass, conformal mounting, wide-angle beam scanning, etc. [1] for NASA's future spaceborne high-gain antennas. It combines some of the best features of microstrip array antenna technology and the traditional parabolic reflector. Recently, the reflectarray antenna has found another horizon. It has the ability to integrate with the solar array and inflatable structures to achieve better overall system efficiency. There is a variety of types of printed reflectarrays. They are formed by basically using different elements, such as patches with variable phase delay lines [2,3] or variable rotation angles [4] and patches, rings, or dipoles with variable sizes [5,6,7]. These printed reflectarrays, although they are different, can be designed in a same fashion by using the simple conventional array technique [3]. Prior to the actual design, several important characteristics of the reflectarray, such as the element pattern, f/D ratio, bandwidth, feed pattern, etc., must be well understood by the designer in order to achieve a design with adequate efficiency.

Reflectarray characteristics: A microstrip reflectarray consists of a thin, flat reflecting surface and an illuminating feed, as shown in Fig. 1. On the reflecting surface, there are many isolated microstrip patch elements without any power division network. The feed illuminates these microstrip elements, which are designed to scatter the incident field with different phases to compensate for the path length differences from the feed and, thus, form a planar scattered phase front. One of the techniques to achieve compensating phases for the elements is to attach different-length phase delay lines to the patch elements. There are several other techniques [4,5,6,7] that can achieve a similar result. Nevertheless, in order to achieve an optimum efficiency for a reflectarray, careful consideration should be given to the following design parameters:

1. *f/D ratio:* As illustrated in Fig. 2, f/D is the ratio of the focal length to the diameter of the reflectarray aperture. The feed horn must have a pattern shape to optimally illuminate the aperture so that the spillover loss can be minimized and the illumination taper on the aperture is more uniform. Typical design curves with only spillover and illumination efficiency considered for a 0.5 m Ka-band reflectarray [8,9] are shown in Fig. 3. Another design curve, that gives the plot of aperture efficiency versus f/D ratio with a given feed pattern shape, is shown in Fig. 4. Design curves similar to the above must be generated for a specific reflectarray to achieve an optimum efficiency.

2. *Element pattern shape:* The effect of the patch element pattern shape must be included in the equations that form the curves in Figs. 3 and 4. The elements that are located at the central region of the aperture should have narrower element beamwidth with higher gain so that more energy can be received and transmitted by these elements. On the other hand, as indicated in Fig. 2, the elements at the edge region of the aperture should have wider element beamwidth so that the incident field, coming from the feed with a large incident angle, can still be mostly received. However, for ease of manufacturing, all elements in the aperture should be identical with the same substrate material. Thus, a tradeoff analysis between the element pattern shape, feed pattern shape, and f/D ratio is critical in achieving a good efficiency for the overall antenna system.

3. *Bandwidth:* The bandwidth performance [8,10] of a microstrip reflectarray is limited by four factors: (1) the feed horn bandwidth, (2) the array element spacing, (3) the microstrip patch element, and (4) the differential spatial phase delay. The last two factors are more band-limiting than the first two.

The microstrip patch element is known to be a narrow-band radiator. Its bandwidth can be increased from the conventional few percent to more than 10% by simply increase the substrate thickness. However, the thicker substrate will result in a more narrow element beamwidth which violates the above item 2 rule that the edge elements must have wide element beamwidth. Therefore, a compromise must be made between the bandwidth and the efficiency. The fourth factor of differential spatial phase delay [10] comes from the fact that the phase delay mechanism is a "phase delay" and not a "time delay". The effect of this differential spatial phase delay on the bandwidth becomes smaller if the f/D ratio is larger and/or the aperture's electrical size is smaller. To demonstrate this point, the calculated −1 dB gain bandwidths of a 32 GHz microstrip reflectarray [8] are tabulated below:

Bandwidth of a 32 GHz Microstrip Reflectarray

f/D	0.5 m diameter	1.0 m diameter
0.5	4.8 %	2.6 %
1.0	8.5 %	4.5 %

4. *Cross-polarization:* With the conventional element arrangement in a reflectarray, the cross-pol radiation is always high in the main beam region. This is because the cross-pol fields of the patches and of the feed horn, similar to the co-pol field, are all coherently directed to the same direction by the same set of phase delay lines. This phenomenon has been observed in the work reported in references 9 and 10. There are several methods to suppress this relatively high cross-pol level in the main beam region by uniquely configuring the patch elements. As shown in Fig. 5, the patch elements can be arranged in an anti-phase configuration for linearly polarized case or in a sequential rotation configuration for circularly polarized field. For circular polarization, the cross-pol can also be suppressed by the rotational technique [9] as shown in Fig. 6. With this technique, the elements, which must be circularly polarized, are all identical except for their angular rotations. The different angular rotations not only provide the needed compensating phases for the elements but also diffuse and therefore suppress the cross-pol fields.

5. *Sidelobe level:* The sidelobes of an electrically large (gain higher than 30 dB) reflectarray are generally low. This is true, not only because the illumination taper from the feed horn lowers the sidelobes, but also because the edge elements on the reflectarray aperture, due to their finite beamwidth and their angular offset from the feed, receive less energy from the feed than the center elements. In other words, a very strong amplitude taper across the aperture is formed. However, the near-in sidelobes of a reflectarray can still be high if the feed blockage and the strut blockage are excessive.

6. *Mutual coupling:* The mutual coupling effect between elements is generally not a concern in designing a microstrip reflectarray. This is true because the mutually coupled fields between the low-profile patch elements are known to be insignificant. This is why the simple conventional array-analysis technique, instead of a more complex method, such as the Moment method or FDTD, will suffice in designing a microstrip reflectarray with a large number of elements.

References:

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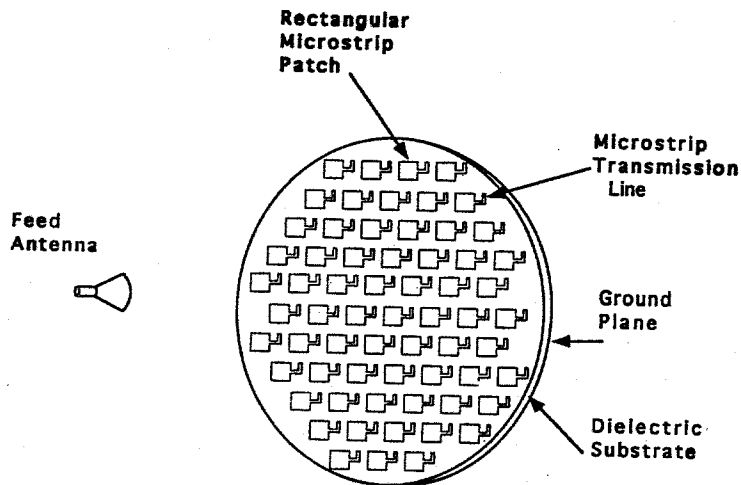
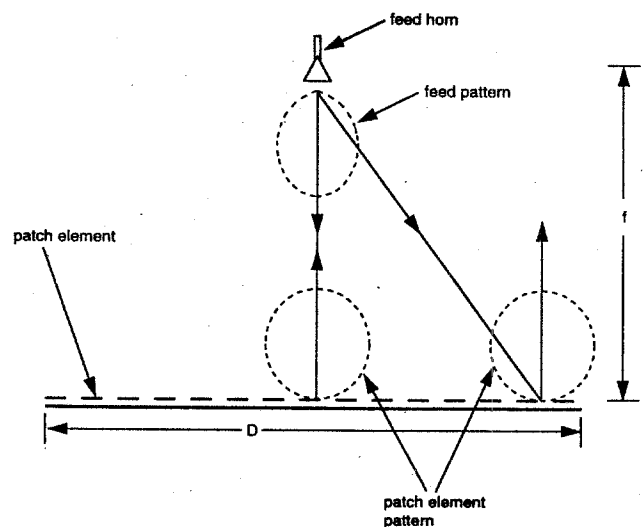Figure 1. Microstrip reflectarray configuration.

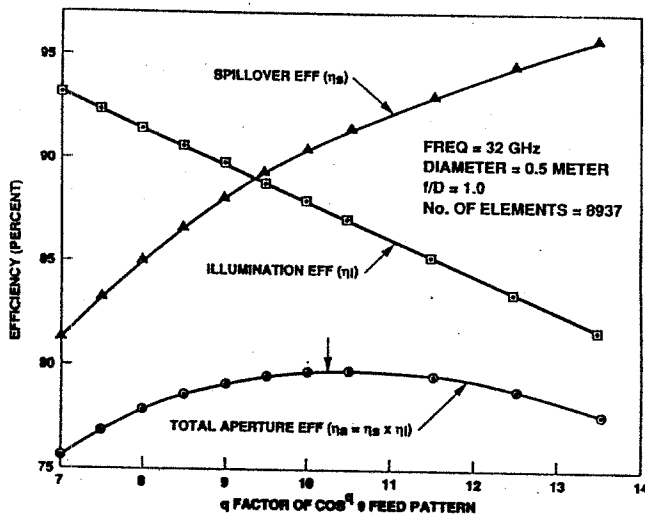Figure 2. Profile view of the microstrip reflectarray.

Figure 3. Design curves for a 0.5m 32 GHz micro-strip reflectarray with spillover loss and illumination efficiency considered.
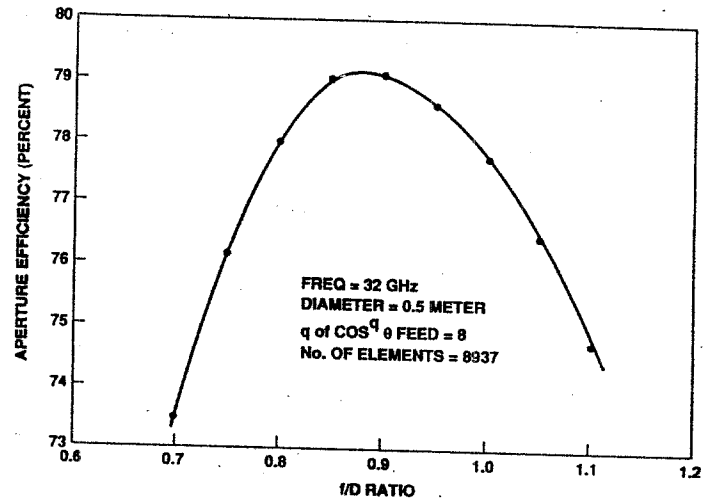

Figure 4. Aperture efficiency versus f/D ratio for the 0.5m 32 GHz reflectarray.
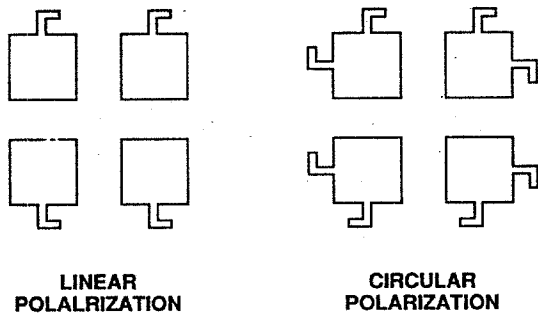

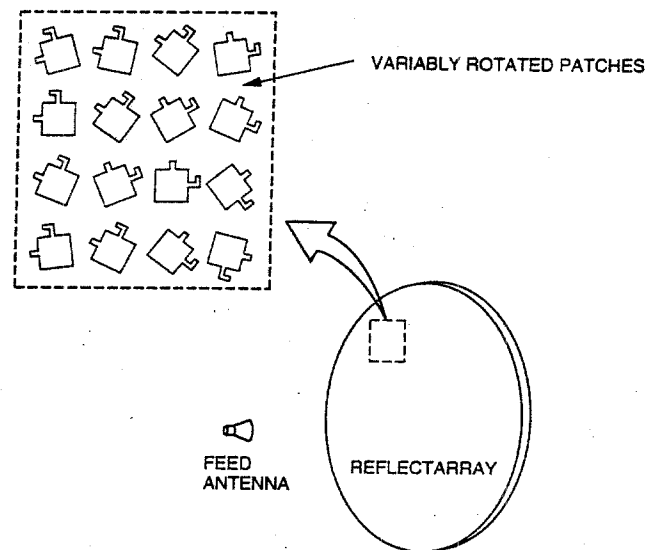Figure 5. Subarray element arrangement to suppress cross-pol radiation.

Figure 6. Element rotational technique to suppress cross-pol of circularly polarized reflectarray.